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PRIMARY BATTERY SESSION. SIMULATED FIELD TESTS ON ZINC-AIR BATT--ETC(U)
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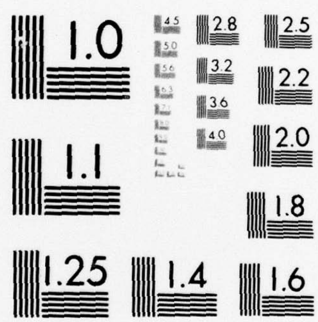

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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(6) Primary Battery Session,

SIMULATED FIELD TESTS ON ZINC-AIR BATTERIES

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Introduction

In recent years considerable interest has been shown by the military and private industry in various zinc-air batteries because of their potentially high energy density. Zinc-air (Zn-Air) batteries may be divided into three categories: (1) the reserve primary battery, activated with water prior to use,[1] (2) the non-reserve primary type,[2] and (3) the mechanically rechargeable type.[3,4,5]

The overall objectives of this simulated field program were to:

1. Evaluate the relative performance of these three types of batteries on continuous drain and moderate to high power intermittent loads.
2. Compare the operational characteristics of batteries using low cost catalysts versus those with more expensive catalysts.
3. Compare blower/heater devices with the hybrid concept (using a suitable nickel-cadmium (Ni-Cd) battery in parallel with a Zn-Air battery) to increase the transmit current capability and low temperature performance of Zn-Air batteries.
4. Compare the performance of 20-cell batteries versus 22-cell batteries, both in continuous discharge modes and as hybrids with Ni-Cd batteries.
5. Compare the performance of batteries tested outdoors with "in-lab" tests.

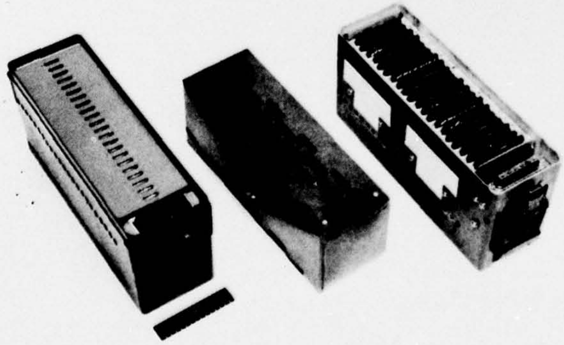

Figure 1. Three Zinc-Air Batteries: BA-535( )/U (Primary Reserve), BA-591( )/U (Primary Non-Reserve)and BA-525( )/U, (Mechanically Rechargeable).

Battery and Test Program Description

Figure 1 shows the three test batteries. The dimension and weight data for the batteries (from left to right as shown in Fig. 1) are given in Table I. All three batteries can be operated in a 24 volt (20 Ah nominal rating) mode or a 12 volt (40 Ah nominal rating) mode. In all the tests conducted, the batteries were used in the 24 V mode. Battery BA-525, the mechanically rechargeable version, has 20 cells, with a platinum air cathode catalyst. Battery BA-535, the primary reserve type, has 22 cells and a silver-mercury air cathode catalyst. Both Battery BA-525 and Battery BA-535 are activated with water prior to use. The primary throw-

TABLE I
BATTERY DIMENSIONS AND WEIGHT DATA

	BA-535	BA-591	BA-525
HEIGHT, IN.	5.5	4.5	5.5
WIDTH, IN.	4.0	4.0	4.0
LENGTH, IN.	12.0	12.0	12.0
VOLUME, IN.^{3}	264.0	216.0	264.0
ACTIVATED WEIGHT, LBS.	3.3	7.5	9.3

TABLE II
TEST PROGRAM
(OUTDOORS)

DUTY CYCLE	DRAIN	TEMPERATURE RANGE (°F)	TEMPERATURE AVERAGE (°F)	AUXILIARY DEVICE	NUMBER OF TESTS BA-525	BA-535	BA-591
CONT	3.0 A	47-53	50	NONE	1	1	1
		26-34	30		1	1	1
		17-23	20		1	1	1
		76-84	80		7	-	-
1:9	7.0A/125 mA	42-47	45	BLOWER/COVER & HEATER	1	1	-
		29-35	32		-	1	-
		22-28	25		-	1	-
1:9	7.0 A/125 mA	33-43	38	BLOWER/COVER NO HEATER	1	1	-
1:9	7.0 A/125 mA	20-28	24	Ni-Cd HYBRID	1	1	1
		30-34	32		1	1	-
		7-13	10		-	-	1
1:9	5.0 A/0.6 A	18-30	24	Ni-Cd HYBRID	1	-	1
1:9	3.0 A/0.6 A	41-49	45	NONE	1	1	1
1:59	3.0 A/0.6 A	26-34	30	NONE	1	1	-
1:19	3.0 A/0.3 A	32-40	36	NONE	1	-	-
1:19	3.0 A/0.3 A	8-20	14	Ni-Cd HYBRID	1	-	-
			"IN-LAB"				
CONT	3.0 A	69-71	70	NONE	1	1	1
		73-85	79		5	-	-
1:9	7.0 A/125 mA	73-77	75	Ni-Cd HYBRID	-	-	1

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away Battery BA-591 is an early prototype of a 24 V non-reserve battery and was fabricated by paralleling two banks of 22 cells. These 15 Ah cells used a gel electrolyte with a low cost manganese catalyst in the air cathode. Battery BA-591 has the simplest activation, namely, tearing open and removing the double film packaging material.

The test program to evaluate the relative performance of the three batteries is shown in Table II.

Discussion of Results

Ampere-hour capacities for each type of battery at 3 A continuous drain and various test temperatures are shown in Table III. It is to be noted that the temperatures listed are

TABLE III
Ah SERVICE AT 3.0 A (TO 20 V CUTOFF)

	"IN-LAB"*		OUTDOORS*			
	79°F WARM START	70°F WARM START	80°F WARM START	50°F WARM START	30°F COLD START	20°F WARM START
BA-525	18.2	21	21.5	25	22	21
BA-591	--	18	--	19.5	18	21
BA-535	--	17	--	15	18	21

* AVERAGE AMBIENT TEMPERATURES DURING TEST DISCHARGE

average temperatures encountered during the tests; however, the tests were actually conducted within the temperature ranges listed in Table II. In all the test data reported, a 20 V cutoff was used. Batteries tested at 30°F were subjected to a "cold-start" condition, i.e., they stood for 20 hours at the outside test temperature after activation and before test. All tests at other temperatures were "warm starts." A warm start is a test started shortly after activation without allowing sufficient time for the battery to reach the equilibrium ambient test temperature. In general, starting internal temperatures for Battery BA 525 and Battery BA-535 were about 70°F above ambient due to the retention of heat of solution. Battery BA-591 generally started at the equilibrium temperature reached during storage (about 50°F, in the outside test shelter). The low capacity of Battery BA-535 at 50°F was due to electrolyte leakage. This battery was very unreliable due to many instances where this leakage problem occurred. Despite a few isolated good results, in many cases two or three batteries had to be activated to obtain one suitable for test.

Figure 2 shows operating characteristics of the three batteries at 20°F. Battery BA-591 and Battery BA-535 gave an energy density of 64 Wh/lb, compared to 53 Wh/lb for Battery BA-525. In the level portion of the discharge, Battery BA-535 has a voltage about 2 V higher than Battery BA-591 even though they both contain 22 cells. This may be due to the different catalysts used in these batteries. The capacity of Battery BA-591 was reduced to 18 Ah for the 70°F tests due to overheating (inner cell temperatures reached over

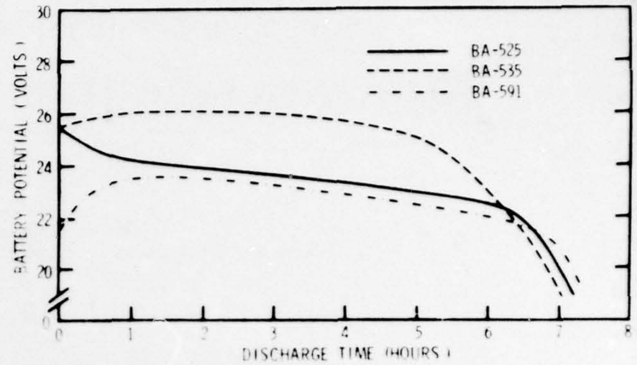

Figure 2. Relative Performance of Batteries BA-525, BA-535 and BA-591 at 3.0 Amperes and 20°F.

200°F). However, it is felt that future designs of Battery BA-591 can be fabricated with improved air flow to yield better performance from 70°F to 120°F.

Air blowers built into the battery cover[4,5] and heaters were used with Batteries BA-525 and BA-535 when these batteries were tested at an average temperature of 45°F on a 1:9 transmit:receive mode at intermittent currents of 7.0 A:125 mA. These auxiliaries were required since the zinc-air batteries gave very poor service when operated alone on such a discharge regime. A thermostat located in the blower cover activated the heater when the air temperature fell under 60°F. The heater (situated in the battery), operable only during the receive cycle, was rated at 24 watts, drawing 880 mA from the battery. The blower, which could only be activated when the battery voltage fell below 24 V (on transmit), required about 150 mA of current. It was observed that neither battery yielded above 9 hours service (7.3 Ah). Battery BA-525 with a blower and no heater, discharged on a similar intermittent mode at an average temperature of 38°F, yielded 7 hours of service. Thus, it was shown that by using the heater in a temperature range of 38° to 45°F, service was increased by two hours. Both batteries had shown service of 20 hours or better at 70°F for this discharge mode with a blower and no heater.

Batteries BA-525 and BA-535 were then tested in the hybrid arrangement in the 1:9 intermittent mode at currents of 7.0A:125 mA with an 18-cell Ni-Cd battery of 1 Ah rated capacity. Battery BA-525 was connected in parallel with Ni-Cd battery, but Battery BA-535 had an electronic voltage control added to its circuitry so that current flow on charge from the Zn-Air battery to the Ni-Cd battery would cease when the Ni-Cd battery reached 26.0 V. This device was used to prevent possible overheating and damage to the Ni-Cd cells, which can occur with a 22:18 Zn-Air: Ni-Cd cell ratio. Figure 3 compares the performance of Battery BA-525 hybrid arrangement tested at 32°F with the blower/heater package tested at 45°F. Separate continuous curves are shown for the receive and transmit cycles. The hybrid arrangement was vastly superior, yielding nearly triple the service (25 hours vs. 9 hours). The performance of Battery BA-535 on similar tests was comparable, with slightly higher voltages.

Comparative tests were conducted on hybrid arrangements of Battery BA-525 and Battery BA-591 when discharged on intermittent moderate to low power applications. While Bat-

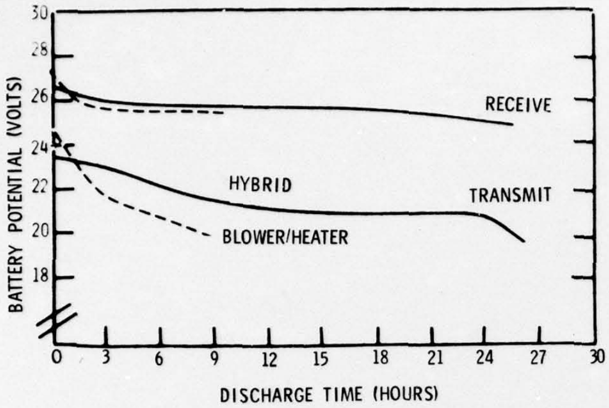

Figure 3. Discharge Curves for BA-525 Comparing Blower Cover and Heater to Hybrid Arrangement.

tery BA-591 showed no advantage in service, it showed a 20% greater energy density due to its lower weight compared to Battery BA-525.

Figure 4 shows Battery BA-591/hybrid performance at

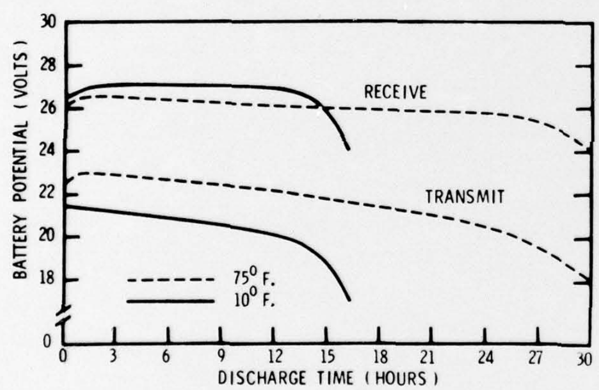

Figure 4. Discharge Curves for BA-591 with Hybrid at 75°F and 10°F.

75°F and 10°F for a 1:9 mode at currents of 7 A:125 mA. The service time of 13 hours at 10°F is about 50% of the capacity at 75°F, quite good considering that a Battery BA-525 hybrid arrangement tested "in-lab" at 0°F yielded just over 5 hours. A Battery BA-591/hybrid arrangement tested in the laboratory yielded 8-½ hours under a similar mode at 0°F.

Additional tests were conducted on Battery BA-525, at 3 A continuous, to determine the effect of outdoors versus "in-lab" testing on battery performance. These tests were conducted over a temperature range of 73-85°F. The battery capacity when tested outdoors at an average temperature of 80°F averaged 21.5 Ah, as shown in Table III. The battery capacity "in-lab" at an average temperature of 79°F averaged 18.2 Ah. The reduction of capacity "in-lab" is attributed to the batteries running warmer. Premature failure indoors can be attributed to cell dryout.

Conclusions

The following general conclusions were derived from these investigations:

1. All three batteries performed well on the 3.0 A continuous drain at temperatures ranging from 20°F to 70°F.
2. The water-activated Battery BA-535 was the most unreliable battery. Repeatedly, two or three batteries had to be activated to obtain one suitable for test.
3. Of the two other types evaluated, Battery BA-591 proved superior in ease of use and gave better energy density when compared to Battery BA-525 in moderate to low power intermittent regimes.
4. For high rate transmit duty cycles and lower temperature use, auxiliary devices are required for battery operation. Hybrid combinations (Ni-Cd and Zn-Air) were far superior to zinc-air batteries with blower/heaters.
5. Battery BA-525 yielded about 15% greater capacity when tested in an outside summer environment as compared to testing at a comparable temperature indoors (at 3.0 A continuous).

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